Fracture Propagation in Multi-Piece Run Flats

Sebastian K. Karwaczynski

TARDEC (Submission To MTU in fulfillment of MEEM 6130), Warren, Michigan,48397

The purpose of this paper is to discuss and present a hypothetical situation using real world experience. In the course of this outline no particular information actual test information such as loads, designs and test results will be revealed. However a hypothetical load, design and test result will be presented typical of what could be expected during run flat testing.

Nomenclature

PM	=	Product Manager
PID	=	Proportional–Integral–Derivative

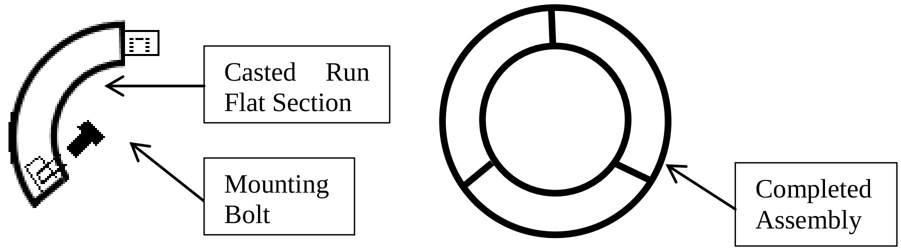
I. Introduction

One of the greatest challenges faced by passenger vehicles is tire life and degradation. As applied on passenger and commercial trucks, tires will last a certain amount of time under "normal" driving conditions. When applied to the Military vehicles tires begin moving beyond conventional usage or "normal" driving conditions. The Military puts demands on their vehicles that at times cannot be defined by lab tests or vehicle level testing. This report will focus on the next step of vehicle mobility once the tire is punctured or destroyed, they run flat. Run flat systems were born out of necessity and provide an essential function to the Military. In conflict areas Soldiers depend on vehicles to get them out of harm's the way a conventional tire system could not provide once damaged. As applied to Fracture Mechanics we will focus on an element of laboratory testing to qualify a run flat system. During this paper a run flat system will be tested on a Tire Test Machine and propagation of cracks within the run flat will be discussed. It is important to note that the design presented here is theoretical and does not utilize existing run flat designs. The design will be of a multi-piece run flat variety and rigid material.

II. Project Background

Early in Jan-2010 a PM office of a particular tactical vehicle approaches the team to develop a new cost effective and robust design for a run flat. If successful other PM offices have expressed interest and in the project and are also willing to fund the project. The current run flat design is heavy, requires special tools to install, very hard to install in the field, has a short shelf life, and is a single piece made of rubber that is susceptible to the same problems the plague tires.

The project team starts to review all the issues and bring in a contractor that has been working on a new design and discussed the possibility of a new design. Being high strung and over caffeinated the Engineer sketches a design that he is extremely proud of and believes that it is state of the art as shown in Figure 1. The design is a multi-piece design that can be assembled inside of the tire itself and requires only basic hand tools. The team reviews it with the contractor and agrees that it could be a good idea and continue with the finalized design.



Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 MAR 2011	**N/A**	**-**

4. TITLE AND SUBTITLE **Fracture Propagation in Multi-Piece Fun Flats**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Sebastian K. Karwaczynski**	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000, USA**	8. PERFORMING ORGANIZATION REPORT NUMBER **21660**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000, USA**	10. SPONSOR/MONITOR’S ACRONYM(S) **TACOM/TARDEC/RDECOM** 11. SPONSOR/MONITOR’S REPORT NUMBER(S) **21660**

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
Submitted to Michigan Technical University in fulfillment of MEEM 6130, The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**8**	

Figure 1. Multi piece run flat sketch

The contractor starts a detailed design that utilizes one tool to create a symmetrical piece which allows three pieces to be bolted together. The first pieces are cast on a soft tool for a fit and finish study, the pieces fits together perfectly. Satisfied with the progress the PM, Team tasked with the project and the contractor push hard to create the first production tooled parts and proceed to testing

III. Testing and Results

Testing of a run flat consists of testing in a laboratory and testing on a vehicle. When tested in a laboratory a fatigue rated testing machine is used as shown in Figure 2. The run flat is first mounted onto a rim (or wheel) and later mounted onto the test machine. The machine has the ability to apply load and various slip and camber angles to simulate “real world” conditions because it is unlikely that a vehicle has the wheels set to exactly 0°. Though for this type of comparison testing the wheel angles are set to 0°. Appropriate loads are applied to the run flat that replicate real world scenarios

Figure 2. Typical fatigue rated testing machine

The team takes the first sample and begins the test. While looking at the real time test data the team notices that the machine is continuously ramping the load up and down, causing the data to look noisy and somewhat harmonic as shown in Figure 3. The reason behind this is that the controller on the machine is trying to compensate for when the run flat joint touches the drive wheel. When these run flats were cast the joint was not taken into account and did not provide a gradual overlap (or transition), instead the gaps have an opening of over 10mm as shown in Figure 4. Within a short amount of time the run flat splits apart and flies off of the rim. The team investigates to find that a crack began to propagate along where the joint exists.

When compared to the test data of a single piece rubber run flat it is clear to see that the amplitude and severity of the data is much lower and uniform vs the previous graph as shown in Figure 5. There are still “peaks and valleys” to the data, but that is from the run out in the run flat. As with tires the run out occurs when there are high spots in the assembly of a tire or run flat. This “Bump” causes the same phenomenon to occur with the controller as before, however since the unit is made of rubber it is much less severe and is able to absorb more energy vs. forcing it to be transferred to the rim and the machine itself.

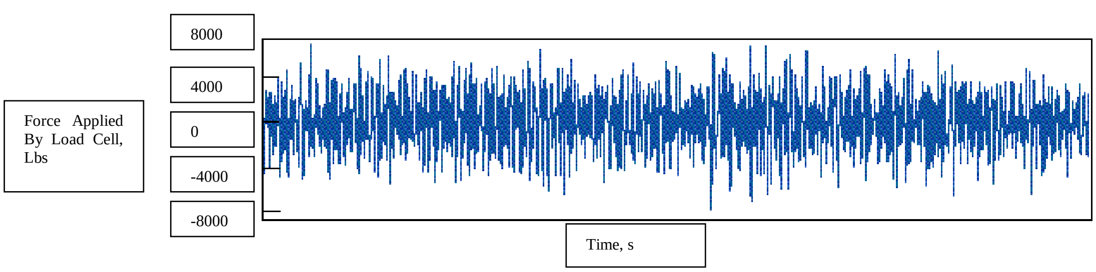


Figure 3. Test data representative of a multi-piece run flat, Load set to 2000 lbs on the controller (generated data, not actual)

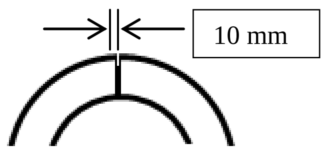


Figure 4. Detail of gap on a multi-piece run flat in the assembled configuration

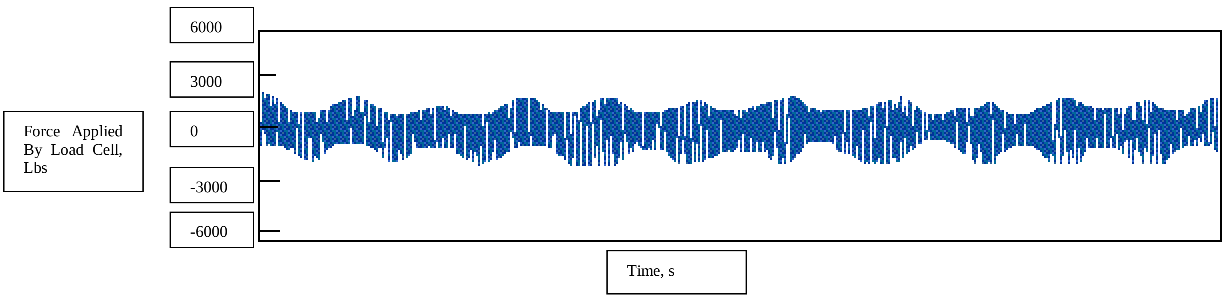


Figure 5. Test data representative of a single piece rubber run flat, Load set to 2000 lbs on the controller (generated data, not actual)

IV. Analysis Of A Multi-Piece Run Flat Crack Propagation

During the inspection process it was noted that the connecting piece which attaches to the mating piece had broken off. The bolt used to attach the two multi-piece run flats together was still in the mating assembly as shown in Figure 6.

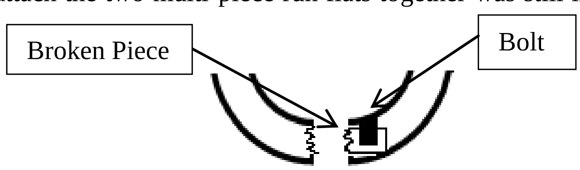


Figure 6. Multi-Piece Run Flat Section Post Test

The cause of the crack propagation is a combination of many factors all of which contribute to the failure.

Test Equipment: It is crucial that the experimenter tunes the PID controller algorithm carefully before test samples are being run on a regular basis. When the lab originally ran the single piece rubber run flat the PID controller algorithm was set properly and tuned for the type of harmonic response which we saw in Figure 5. For a multi-piece run flat the system that doesn't have smooth transitions between pieces (as shown in Figure 4) the machine will try to continuously adjust loads and depending at which speed the run flat is spinning it may be difficult to properly tune it

Heat: Single piece run flats and multi-piece run flats produce heat (thermal component) during testing. The surface that comes in contact with the testing machine and the side of the run flat will see a steady rise in temperature. Meanwhile inside the run flat assembly itself (closer to the rim) the temperature can potentially be a magnitude (2, 3, 4 maybe even 5 times) higher than what is seen on the surface which will be dependent of the type of material that is used in the design. There is a possibility for the inner part of the run flat to become soft, pliable and at times resemble a molten fluid where the relation of shear stress and shear rate is not linear and can be time-dependent (Molten fluids being a Non Newtonian type of material such as cake batter, ketchup, custard, toothpaste, etc.). Hypothetically if we were to increase the temperature of the unit we could potentially raise the temperature enough to where it could become Newtonian in flow thus resulting in a liquid state representative to that that of what would be seen in its original "Casting State" (like taking Jell-O (any flavor) out of the fridge (assuming it has been sitting for over 24 hours) and putting it into the microwave, that delicious gelatinous treat reverts to a liquid state recreating the moment the powder was mixed with boiling water).

Run Flat Material: In this hypothetical situation we assume that the material itself is a good thermal insulator. So the material does not let heat pass through to the surrounding atmosphere (or past that of the boundary layer) easily, thus keeping it within the assembly itself. As we discussed earlier we assumed that the heat contributed in the

degradation of this particular design of the multi-piece run flat. It is up to the team to design a multi-piece run flat that will be able to provide the best product available to the Soldier. As with any design there are tradeoffs such as weight, cost, manufacturability, shelf life, Etc. If we were to use a material that would absorb energy well and dissipate heat would it be suitable so that the run flat could withstand other terrains and changes in temperature? Similarly if we used a material that would be "stiff" (not absorb energy as well) would we potentially start transferring energy through the vehicle system (Rim, suspension, frame, seats, etc.)? The priority is to provide mobility to the Soldier, it might not be comfortable, fast or ideal but it has to work!

Gaps Between Multi-Piece Run Flats (Non Smooth Transitions): Could we have forgotten something? We have been focusing quite a bit on heat is there something else? Reviewing the generated test data above we are reminded of the ups and downs in the test data. That's right! The gaps were causing great stress on our machine, could this also contribute? Every time the joint (or transition) comes in contact with the machine we see compression, HOWEVER we still have two more joints. The remaining joints go into tension as soon as the contacting joint goes into compression. The joints see compression that goes to tension back to compression over and over again. The speed at which we are testing will also affect how these joints flex and give, the faster we go the less time the joints will have to recover before they go into tension. If we were to test our multi-piece run flat slowly the joints would recover faster before going into tension. This cyclical action is where our crack propagation begins

Deflection: In this example we will assume that deflection is 10mm when the test load is applied. This is important because as the joints are being compressed they are also deforming in that area.

Now that we reviewed a majority of what causes multi-piece run flat failure we can focus our efforts on crack propagation. Figure 7 contains a diagram and explanation of the forces acting upon the multi-piece run flat, rim, and the fatigue rated testing machine. You will notice that the bolts were not included in the diagram. They do provide a force, however they were omitted to allow for the moments to be drawn on the run flat connector pieces. As we will see the part does not fail when in compression, it is when it goes into tension that the forces and resulting moment cause crack propagation. Eventually these forces will cause a crack to initiate and propagate. As the crack propagates to a critical length the multi-piece run flat violently separates from the rim

INTENTIONALLY LEFT BLANK, DIAGRAM CONTINUED ON NEXT PAGE

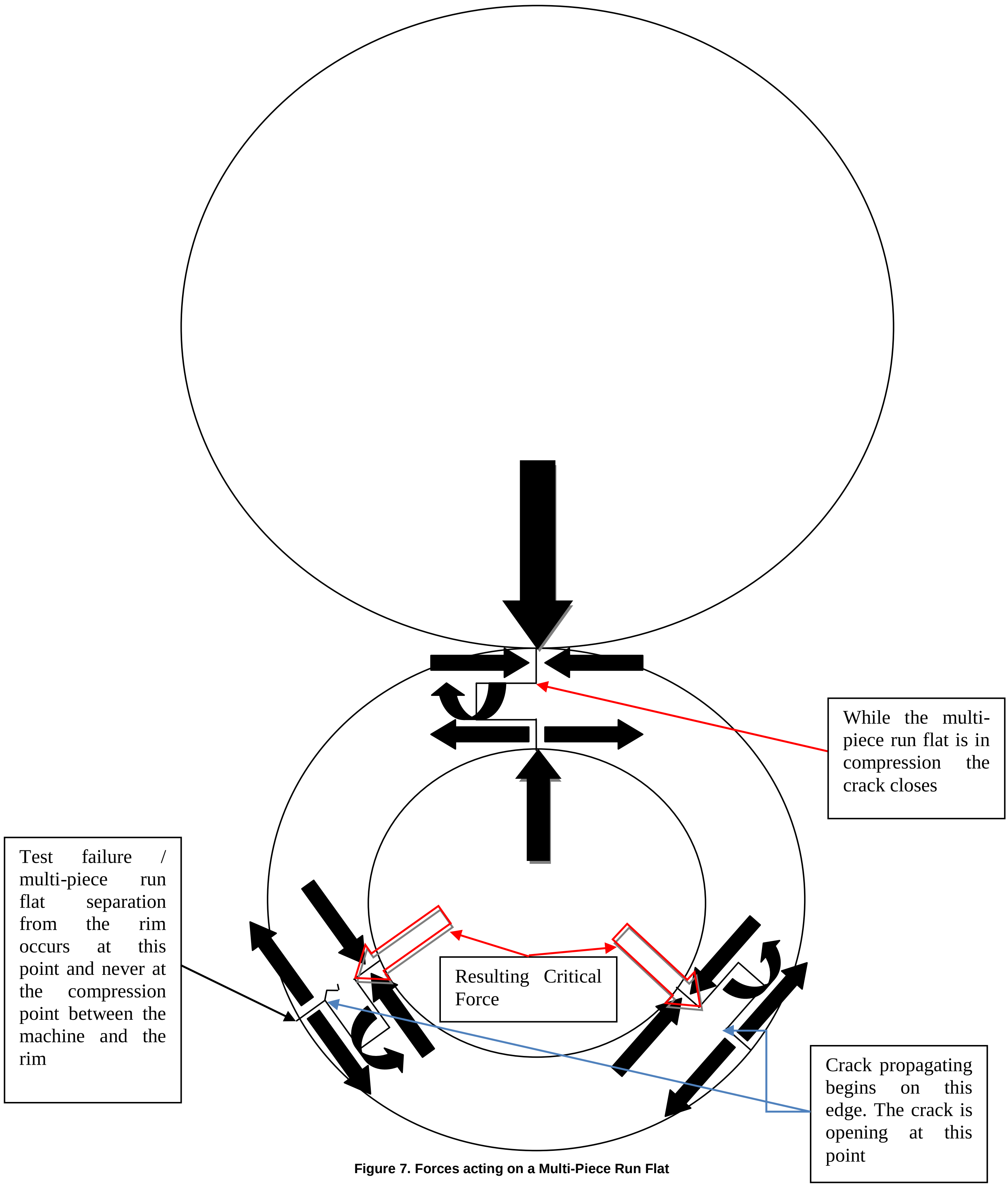


Figure 7. Forces acting on a Multi-Piece Run Flat

We have seen how the forces act on the complete system, we can now focus on the part of the multi-piece run flat where tension occurs. Figure 8 is a zoomed in view of all the forces acting on the part that is in tension. This failure is considered a Mode I failure, that has a combination of forces to drive it to failure. If you look back at our design you will remember the 10 mm gap between the multi-piece run flat sections. Since this gap was closing every time the multi-piece section went into compression. This closing forced the opening on the already open gap on the other section to become much more critical. So in our future design to counteract this we will have to implement creative measures to make sure we can meet our testing specification while not going over budget and past our time line.

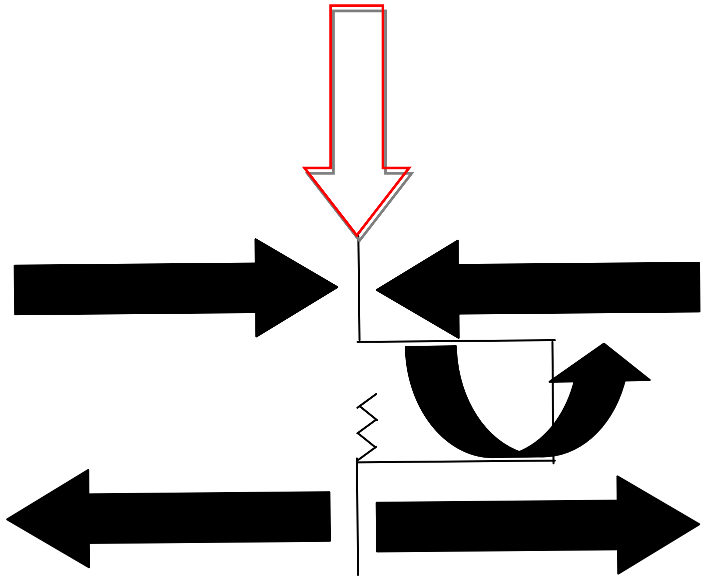


Figure 8. Zoomed in view of Multi-Piece Run Flat in Tension

V. Part Redesign And Improvement

We've now seen how all of the crucial factors played a key role in the separation of our multi-piece run flat. Now our team has decided on a redesign of the mold used to create the run flat, this redesign should help prevent what happened in the past. Figure 9 illustrates the new design, in this design gaps no longer exist between the transition points.

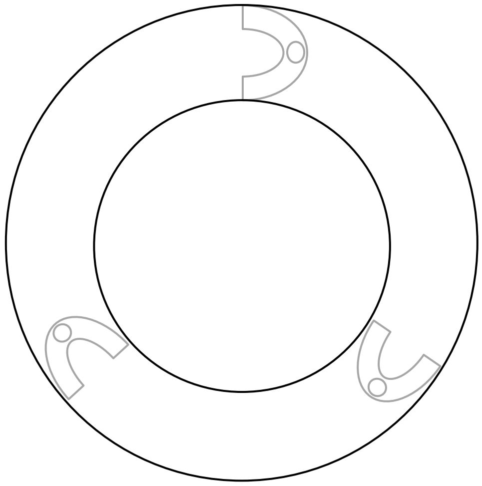


Figure 9. Redesigned Multi-Piece Run Flat

The new Horse Shoe inspired run flat utilizes bolts from the flange face of the multi-piece run flat vs from the inside. Even though this will require more work to assemble it helps eliminate sharp corners, instead radiused corners are utilized (please note the drawing may look as if there are sharp corners, however since this was drawn in Word I was not able to create a smooth transition between edges. One must use their imagination). In addition to before there are no gaps between the sections because they slide into each other and have a transition to them. During testing this should absorb help eliminate the flexing that we saw before.

Now the design was put to the test and it was found that the test data resembled that of the test data from the single piece rubber run flat (see figure 10).

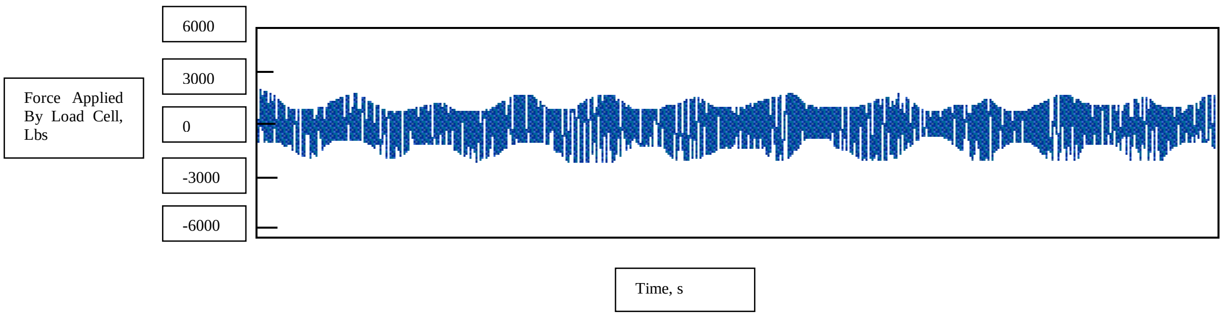


Figure 10. Redesigned Multi-Piece Run Flat Test Data

The “peaks and valleys” this time are still caused by the joints moving relative to each other, however the movement is minor and predictable in nature. It was found that during testing the Horse Shoe multi-piece run flats they were able to last much longer. The machine would shut down due to a test time limitation which the controller software had programed into it years ago (no test specimen had ever lasted that long). It was also noted that heat within the assembly did cause the inner part of the Horse Shoe multi-piece run flat assembly to become Molten as before, however this phenomenon would occur late during testing and even when pieces did come off, the assembly itself was already past the required time limit and therefore judged OK.

In all fairness we should revisit all the previous issues that affected our multi-piece run flat before and investigate any differences we see in our Horse Shoe multi-piece run flat

Test Equipment: The new Horse Show multi-piece run flat reacts differently to our system. We found that we were able to tune our PID controller similarly to that of a single piece run flat and produce favorable results (see figure 10)

Heat: The item still produces the same effect in regards to heat due to the item still being cast out of the same material as before. All considerations are held constant due to this

Run Flat Material: The new design is still casted out of the same material

Gaps Between Multi-Piece Run Flats (Non Smooth Transitions): We now have control over our design and no longer have any transitions gaps. Now every time the joint (or transition) comes in contact with the machine we still see compression, HOWEVER the compression does not cause the gap to close. Therefore since we no longer have to deal with any gaps the relative motion of the joint is much lower thus causing less tension in the remaining two sections.

Deflection: Since the material is the same the deflection of the entire assembly is still the same. The joints are being compressed they are also deforming in that area, consistent to that of the above example.

The Horse Shoe multi-piece run flat was approved to move onto field testing where it proved successful. The PM implemented the change and the team was rewarded for the enhancements they provided to the field of mobility and providing the Soldier with the best run flat possible.

VI. Conclusion

During the design process of a multi-piece run flat the design team will have to be very careful of how they design the assembly. In this hypothetical design we only touched upon some of the key factors that make up the system. Once mounted onto a vehicle terrain, climate, maintenance, etc. will all play a factor in how well a system performs. The fracture that occurred in this design was one that could not be easily serviced. Drilling a hole at the tip of the crack could prove temporary relief, however disassembling the multi-piece run flat to do so is not practical. Smooth transitions and utilizing a design that has a smooth radius at the point at which both pieces meet could potentially eliminate fractures. In terms of practicality and service the Horse Shoe multi-piece run flat would provide the best given performance to the Soldier. Once mounted onto a vehicle the hope is that the run flat system would never have to be used, however should it be called upon at any time it should be able to perform without any issues and get the Soldier back safely.

References

[1]Chant Engineering Co. Inc., Testing Machine: Tire Testing, URL: http://www.chantengineering.com/tiretesting.php [cited 12 March 2011].

[2]Gregory E. van der Vink, IRIS Consortium and Terry Wallace, The University of Arizona, "The Political Sensitivity of Earthquake Locations", Figure 2. Seismic recordings of the January 13 event from the ARCESS array in Norway and the SPITZ array in Spitzbergen, URL: http://www.iris.iris.edu/newsletter/fallnews/political.html [cited 12 March 2011].